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MORPHOLOGY AND ECOLOGY OF THE DEEP FORE REEF SLOPE AT OSPREY REEF, (CORAL SEA)

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ABSTRACT

The deep fore reef slope of Osprey Reef has been surveyed by direct observation by the use of the research submersible SP350, to a depth of 240 m. Submersible dives at three sites indicated a very steep, to almost vertical fore reef slope with numerous ledges and overhangs. Evidence of subaerial erosion and bare reef rock substratum have been observed at depths below 100 m. The epibenthos is characterized by a dominance of encrusting coralline algae and octocorals on the vertical walls between 20 and 80 m. Substratum cover decreases rapidly below 80 m, with only very few scleractinian corals extending to 100 m. The deeper part of the fore reef revealed only a few antipatharians and gorgonaceans. The major factors controlling the distribution of sessile organisms on the deep fore reef slope are discussed.

INTRODUCTION

The first *scientific* investigations of coral reefs with small manned submersibles were carried out in Jamaica with *Nekton Gamma* as early as 1972 (Lang 1974). Yet, there still exist only very few studies of coral reef deep fore reef slopes with submersibles, particularly in the Indo-Pacific. In the Red Sea, Fricke & Schuhmacher (1983) using the submersible *Geo*, studied the depth limits of scleractinian corals, whereas in the Pacific, Agegian & Abbott (1985) reported on deep water macroalgal assemblages at Johnston Atoll and Hawaii (Penguin Bank), using *Makali'i*. Also in Hawaii, Grigg (1975, 1976) investigated precious coral fisheries with the submersible *Star II*, but this study did not include the reef environment proper. Although *Makali'i* was extensively used at Enewetak atoll (Enewetak Submersible Project 1982), only detailed studies on the articulate calcified alga *Halimeda* have so far been published (Hillis-Colinvaux 1985, 1986).

Off the East Australian coast and in the Coral Sea, the only two research submersibles to have been deployed are the *Yomiuri* and *Platypus*.

Orme (1977) described the results of the investigations carried out at Coringa Bank and Flinders Reef with the *Yomiuri* while the only published data which followed the deployment of the *Platypus* at a number of sites along the Great Barrier Reef refer to the *Halimeda* banks on the continental shelf (to 55 m deep) behind the "ribbon reefs" (Phipps *et al.* 1985). There is therefore very little information resulting from direct observations available to date on the morphology and organismic assemblage of the deep fore reef slope in the Indo-Pacific in general, and on the reefs of North Eastern Australia in particular.

Orme's (1977) results indicate that reef building scleractinian corals do not extend below 55 m at Coringa Bank while Hopley (pers. com.) observed large colonies of *Pachyseris* down to about 90 m at Myrmidon reef. Other conspicuous groups of benthic organisms recorded by Orme from the deep fore reef slope of Coringa Bank and Flinders Reef are algae (specifically *Halimeda* and crustose red algae), sponges, hydroids, gorgonaceans, antipatharians and stalked crinoids.

MATERIAL AND METHODS

1. The Submersible

The exploration and research submersible SP 350 (Captain Cousteau's "Diving Saucer") launched in 1959, is a two man diving craft, owned and operated by Campagnes Oceanographiques Francaises, Monaco. Although it can be deployed independently, it is most often deployed from the vessel "Calypso". Maximum operational depth is 350 m. The submersible is propelled by two hydrojets which can rotate 270° from forward to the vertical. They are activated by a pump driven by a 1.5 kw D.C. electric motor powered by external batteries. A hydraulically driven manipulator arm, with two degrees of freedom allows for specimen sampling. Two 16 mm external cine cameras with a 2.5 kw light source provide for high quality image recording. They can be complemented by 35 mm still camera and video recording equipment taken inboard and operated through the viewports. The fine adjustment of buoyancy control, and the remarkable manoeuverability of SP 350, including a ± 30° vertical tilt make her a vehicle ideally suited to the detailed study of vertical or near-vertical submarine slopes.

2. Study Sites

The submersible dive sites were located on the Northwest (leeward) side and at the North horn of Osprey Reef, an atoll shaped reef, situated by 13°53'S and 146°35'E in the Coral Sea and approximately 60 nautical miles NE of the nearest Australian Continental Shelf margin. The lagoon is 35 m deep and approximately 15.5 nautical miles in its largest axis, oriented SSE-NNW. No intertidal or emerged sand cay is to be found on the reef flat which remains immersed, except during low water spring tides.

Three submersible diving sites (Fig. 1) were selected amongst a number of sites surveyed down to 60 m deep by SCUBA during previous expeditions for a qualitative recording of the distribution of scleractinian corals and other major reef dwellers. The preliminary surveys using SCUBA, complemented by echo-soundings, provided evidence of a near-vertical drop off down to at least 300 m at sites 1 and 2 whereas at site 3, on the part of the reef exposed to the north, the upper cliff face (0 - 60 m) was followed by a steep slope, interrupted by a narrow terrace at ca. 100 m depth. Sites 1 and 2 are on the protected side of the atoll, while site 3, without being directly exposed to the swell generated by E to SE trade winds is nevertheless in a higher hydrodynamic energy environment. Maximum depths reached by the submersible were 180 m (site 1), 240 m (site 2) and 140 m (site 3).

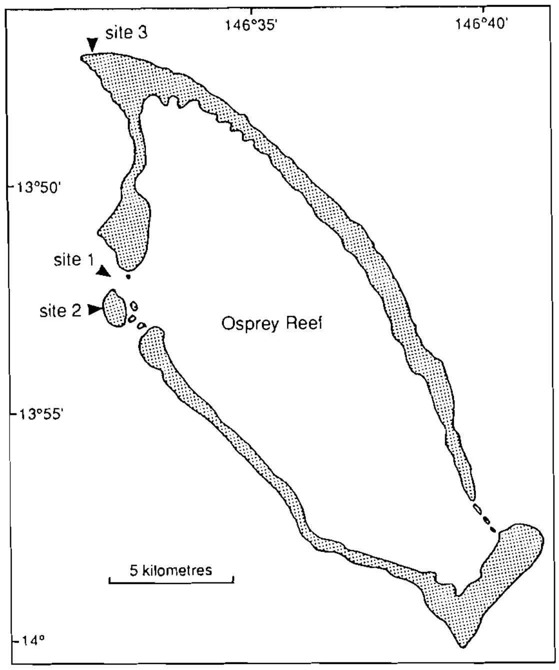

Figure 1. Osprey Reef and location of the submersible dive sites.

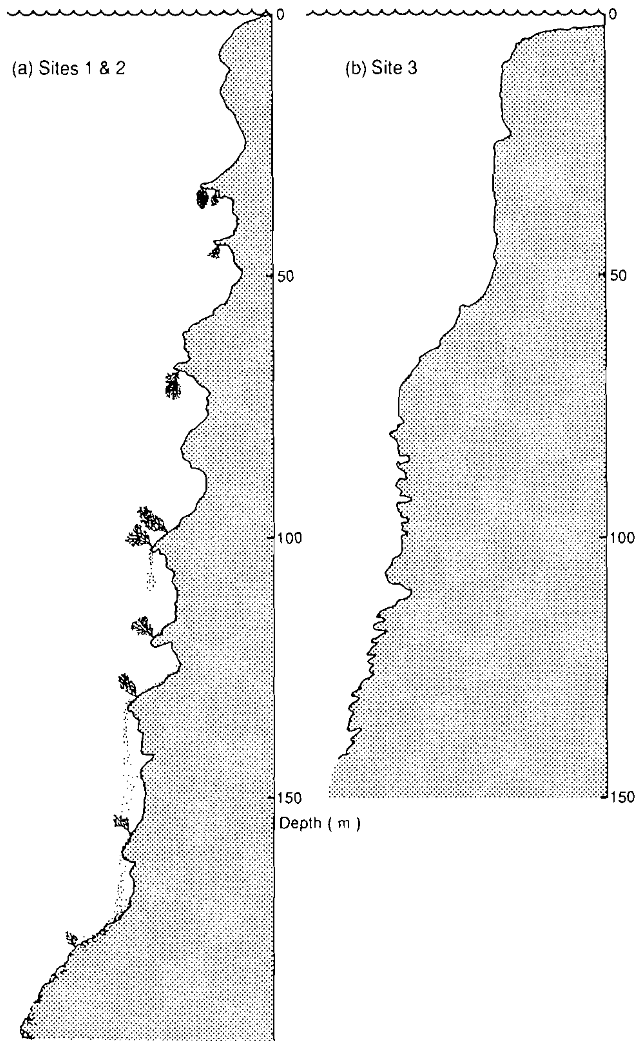

Figure 2(a). Reef slope depth profile at sites (1) and (2).

Figure 2(b). Reef slope depth profile at site (3).

FORE REEF SLOPE MORPHOLOGY

Reef slope topographic profiles and major morphological features are illustrated in Fig. 2. There was considerable similarity between the profiles at sites 1 and 2, which are represented in Fig. 2a by a single drawing, whereas the characteristic profile at site 3 is given in Fig. 2b.

Sites 1 and 2 show a very steeply inclined, nearly vertical wall down to at least 180 m. In more detail however, the topography of the slope is quite complex. The reef flat margin is followed between 0 and ca. 10 - 15 m by a convex slope inclined at 45° on average. Below, the slope becomes vertical for a few metres, then overhanging. A narrow step or terrace is generally observed between 30 and 35 m, followed again by a vertical drop-off ending at 60 to 65 m onto another narrow terrace, partly covered by reef sediment. In detail however, the wall extending between the two terraces shows a succession of ledges and overhanging substratum. The same type of topography extends further down, with an alternation of vertical or over hanging walls interrupted by irregular ledges protruding from the wall, the upper surface of which is partly covered by sediment. The amount of sediment deposited on the upper surface of the ledges increases markedly with depth.

The most characteristic features of the reef slope morphology at sites 1 and 2 are as follows:

- the drop off is nearly vertical, albeit interrupted by a series of ledges, three of which at ca. 30-35, 60-65 and 100 m are larger and can be termed terraces.

- Below 150 m, the vertical, overhanging reef wall is totally devoid of epifauna (and epiflora), leaving exposed a bare cream-beige compact limestone rock. In a few instances the bare rock was observed to be pitted with alveolae ca. 15-25 cm diameter.

  Below 130-150 m cascades of sediment, mostly composed of *Halimeda* fragments, were observed to flow continuously down from successive ledges towards the fore reef basal scree which was observed below 190 m.

At site 3, on the north side of Osprey Atoll, the upper slope angle is much less steep than at sites 1 and 2, and varies between 45 and 60°. A series of sub-horizontal steps poorly covered by fallen reef material and very fine white sand alternate with vertical walls, down to 70 m.

A nearly vertical drop-off only interrupted by small ledges, extends between 70 and 110 m. On the vertical walls the existence of small cavities, caves, crevices or hemispherical excavations 10-40 cm in diameter (Fig. 3) provide evidence of subaerial erosion. Similarly a characteristic erosion notch at a depth of about 110 m is most likely to be an inheritance of a lower sea level stand still.

Below 110 m (and at least down to 140 m) the slope is less steep (70-80°) than between 70 and 110 m and takes the aspect of a series of steeply inclined steps. Fine white sand or mud covers approximately 80% of the substratum with a corresponding decrease in abundance of the sessile epilithic fauna.

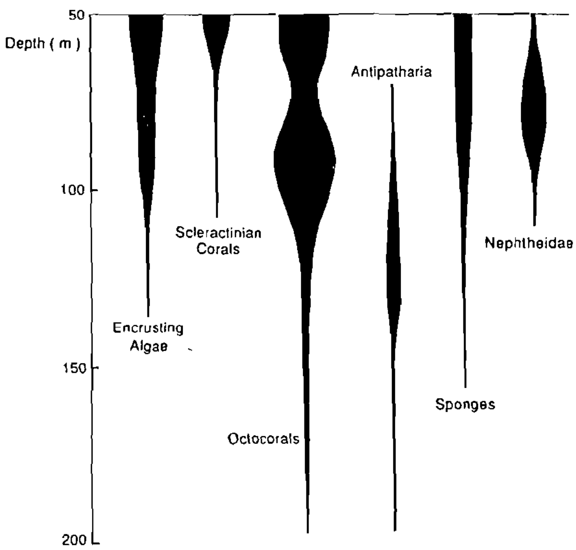

Figure 3. Depth distribution of the major groups of benthic invertebrates (Width of trace is a qualitative index of relative abundance).

FORE REEF SLOPE ECOLOGY

The community structure and zonation on the reef slope are broadly similar at the three sites and a synthesis of the observations is given.

Zone 1: From the reef flat to 12 m

The margin of the reef flat and the upper slope are dominated by encrusting coralline algae, especially *Porolithon onkodes*. Although *Halimeda* spp are present, they remain inconspicuous, as a consequence of their preferential localisation in the small cavities and crevices of the substratum. Scleractinian corals are represented by *Acropora gemmifera*, *A. monticulosa*, *A. humilis*, more particularly near the reef flat margin where they occur with *Millepora platyphylla* and *Lobophytum* sp., both giving a typically encrusting growth form. Massive *Porites* and *Diploastrea heliopora* (in large, somewhat flattened colonies) are mostly observed below 5 m. The presence of *Pocillopora verrucosa* and *Stylophora mordax* is also noted. Although both species are characteristic of this upper zone, they remain uncommon.

Zone 2: From 12 to 50 m

The slope is nearly vertical, but in detail is composed of a succession of ledges and overhanging substratum. In either case, encrusting coralline algae still dominate in terms of lower stratum cover but to a lesser degree than in Zone 1. *Halimeda* spp are less "cryptic" than in the upper slope. Scleractinian corals are restricted to the upper side of the ledges with the exception of occasionally very large colonies of *Diploastrea heliopora* and have a low substratum cover. The commonest species include *Acropora valida*, *A. hyacinthus*, *Porites* spp, *Montipora* spp and several faviidae. These species disappear progressively in the deeper part of this zone, where they are replaced by *Pachyseris speciosa*, *Leptoseris* spp and *Mycedium elephantotus*. Other characteristic components of the community are the sea fans (gorgonacea) species *Suberogorgia mollis*, *Melithea* sp and *Ctenicella pectinata*, the latter being uncommon.

Under the ledges, the only scleractinian corals recorded are *Dendrophyllia micrantha* and small encrusting colonies of *Stylocoeniella guentheri* and *Psammocora explanulata*. The underside of ledges is dominated by octocorals, often in dense populations (Fig. 4) (genera *Siphonogorgia* and *Carijoa*, together with a representative of the family Acanthogorgiidae).

Zone 3:

As reported above, the morphology of the slope between 50 and 70-80 m is different between site 1 and 2 and site 3. At all sites, however, this part of the fore reef slope is, from an ecological standpoint, impoverished compared to the 12-50 m zone immediately above:

- The skiophilous octocorals (Acanthogorgidae, *Siphonogorgia*, *Carijoa*) decrease rapidly in abundance and disappear.
- The only scleractinian corals recorded belong to the Agariciidae and Pectiniidae (*Leptoseris hawaiiensis*, *Pachyseris speciosa*, *Mycedium elephantotus*, *Echinophyllia aspera*).

This impoverishment is mitigated by the appearance of species not recorded in shallower water, in particular nephtheid alcyonaceans (notably the genus *Spongodes* which can be represented by very large colonies), gorgonaceans and several species of *Antipathes*.

Zone 4: From 70-80 m to 150 m

On the part of the deep fore reef slope extending between 80 and 150 m, the substratum cover by encrusting calcareous algae decreases markedly. The result is that, toward the lower margin of the zone, large areas of the substratum (particularly in the vertical or overhanging parts) are left completely bare. Calcareous algae were not recorded below 150 m.

The only scleractinian species in this zone are *Leptoseris hawaiiensis* and *Pachyseris speciosa* which were not observed below 100 m. The sessile fauna is dominated by the gorgonaceans (including some very large *Suberogorgia mollis*). The other components are alcyonaceans (*Spongodes*), antipatharians, sponges (several species, some of which are conspicuously encrusting) and, on the overhanging walls with a very low substratum cover, some very large (25-30 cm) Spondylidae.

With increasing depth, the upper surface of the ledges is increasingly covered by a white, fine sediment. At site 3 the increase in sediment deposits below 110 m leads to a reduction in the sessile fauna mostly represented by stunted *Suberogorgia* and restricts the remaining encrusting calcareous algae to the more steeply inclined areas, devoid of sediment deposits.

Zone 5: Below 150 m

The fauna of the deep fore reef slope below 150 m is very depauperate, and the increase in the surface area covered by sedimentary deposits on non-vertical surfaces (particularly below 180 m) further accentuates this impoverishment. The most remarkable components of the epifauna are sponges (down to ca. 170 m), *Antipathes* and *Suberogorgia* with colonies which are increasingly scraggy with depth.

In summary, the deep fore reef slope (below 50 m) is characterised by:

- a paucity of scleractinian corals which are represented only by genera of the families Agariciidae and Pectiniidae, and which do not extend beyond 100 m
- the relative abundance and diversity of gorgonaceans, and the presence of nephtheid alcyonaceans and sponges down to 150 m.
- much impoverished fauna, with essentially gorgonaceans and sponges below 150 m.

Fishes

A detailed analysis of the fish fauna of the reef slope proper (0-50 m) is beyond the scope of this paper. In this zone the fish fauna is not significantly different from that of the slopes of the Great Barrier Reef, albeit more diverse and abundant. The pelagic component is particularly developed, with large schools of Carangidae (*Caranx sexfasciatus*, *C. melampigus*, *C. lugubris*, *C. fulvogutatus*), *Sphyrena* sp, *Gymnosarda unicolor* and several species of sharks.

On account of the vertical character of the deep fore reef slope, benthic fishes are very few in number. They are represented by a few individuals belonging to the genera *Cephalopholis* and *Plectropomus*. The pelagic fish fauna exhibits a clear zonation. The carangidae cited above extend down to ca. 70-80 m together with several species of Acanthuridae and the sharks. Below 80 m, a reduction of the ichthyofauna is observed with the disappearance of the Acanthuridae and Carangidae. A few Lethrinidae (*Lethrinus chrysostomus*) are conspicuous down to 150 m. On the lower part of the deep fore reef slope only a few individuals belonging to the Lutjanidae have been recorded: *Pristipomoides* between 150 and 200 m and *Etelis* at the deepest point of the dives (210 m, site 2).

DISCUSSION AND CONCLUSIONS

From a morphological standpoint, the major characteristic of the deep fore reef slope at Osprey Reef is its steepness. Submersible observations, complemented by echo soundings reveal that on the whole of the leeward side, the slope is vertical or nearly vertical with a narrow, but conspicuous terrace at ca. 60-65 m. Vertical deep drop offs have also been reported below 70 m from the slopes of Ribbon No. 5 on the Central Great Barrier Reef, with ledges, caves, overhangs, small sediment chutes and a basal scree at a depth of 200 m (Hopley, pers. comm.). Although the upper slope (0-70 m) of Ribbon No. 5 is much less steep than that of Osprey Reef, there is a striking morphological similarity between the deep fore reef slope of the two reefs. This is in sharp contrast with the fore reef slopes of Flinders Reef and particularly Coringa, on the Coral Sea plateau which are much less steep, especially at Coringa (Orme 1977). These differences in the morphological structure of the deep fore reef slope may suggest a different origin and geological history for the reefs of the Queensland Plateau.

The deepest scleractinian corals at Osprey were observed at 100 m. At Myrmidon (Hopley, pers. comm.), they have been recorded down to 110 m. In both instances these corals belong to the genera *Leptoseris* and *Pachyseris* (family Agariciidae) and to *Mycedium* and *Echinophyllia* (family Pectiniidae). While it is recognized that information on the depth distribution of scleractinian corals on the Great Barrier Reef and in the Coral Sea is still fragmentary, the data given above are very similar to those collected by Fricke & Schuhmacher (1983) during an intensive survey in the Red Sea. There, 7 out of 9 species of hermatypic scleractinians extending to 100 m or beyond belong to one of the two families Agariciidae and Pectiniidae. With one exception, referred to as *Leptoseris fragilis*, these species do not extend beyond 108 m.

The scleractinian fauna of the deep fore reef slope in the Red Sea is apparently more diverse: Fricke & Schuhmacher (1983) list 36 zooxanthellate species belonging to the Pocilloporidae, Acroporidae, Siderastreidae, Agariciidae, Fungiidae, Poritidae, Faviidae, Merulinidae, Mussidae, Pectiniidae and Caryophylliidae. This probably is a result from a much more intensive sampling in the Red Sea. Casual observations indicate that species belonging to the same families do extend to beyond 70 m on the slopes of the outer Great Barrier Reef or on the slopes of the reefs in the Coral Sea (Pichon, unpublished).

It is also to be noted that a number of species recorded only below 60 m by Fricke & Schuhmacher (1983) also exist in shallower water, both in the Red Sea and in the Great Barrier Reef. This is the case, for instance, for *Leptoseris gardineri*, *Cocsinaraea wellsi* and *Goniastrea palauensis*.

The data on depth distribution of zooxanthellate scleractinians presented by Kuhlmann (1983) are more difficult to interpret. As they are obtained from dredge hauls, there is much uncertainty as to the exact depth of the occurrence of the species. Of the six species (Table 1) which are reported to extend beyond 100 m by Kuhlmann, two belong to the Agariciidae (*Leptoseris porosa* and *Pachyseris speciosa*) and one to the Pectiniidae (*Echinophyllia aspera*).

Table 1. Indopacific zooxanthellate scleractinia extending beyond 100 m (data from Kühlmann 1983).

Species	Max depth (m)
Psammocora explanulata	140
Montipora verrucosa	265
Pachyseris speciosa	203
Coscinaraea monile	270
Echinophyllia aspera	180

At Bikini (Marshall Islands) the results of dredgings on the outer reef slope led Wells (1954) to define an "*Echinophyllia* zone" (where *E. aspera* and *Oxypora lacera* are dominant) between 18 and 90 m, and a "*Leptoseris* zone" extending down to 145 m dominated by several species of that genus (*L. hawaiiensis*, *L. papyracea*, *L. scabra* and *L. solida*), but where both *Echinophyllia aspera* and *Pachyseris speciosa* are reported as well.

At the scale of the entire Indopacific, Pichon (1979) reported that both genera *Echinophyllia* and *Pachyseris* co-occur in most of their respective depth range and that the deepest zooxanthellate scleractinian community on the fore-reef slope is characterized by Agariciidae and Pectiniidae. The scleractinian species observed at Osprey Reef between 70 and 110 m represent an impoverished aspect of this

Agariciidae - Pectiniidae community. The extreme steepness of the fore reef slope of Osprey Reef could be at least in part responsible for the impoverishment noted. Indeed, Fricke & Schuhmacher (1983) observed that along vertical walls in the Red Sea zooxanthellate corals disappear at 70-80 m deep, and they suggest that, on vertical cliffs, light intensity is decreased due to the loss of bottom reflection and light diffusion in the water mass.

It should be stressed that these considerations apply to the deep fore reef slope (below 50 m) only and therefore do not conflict with the finding by Kuhlmann (1983) that "steep slopes with an angle of inclination between 50 and 80° and at depths between 20 and 50 m are particularly suited for colonization by deep water (*sic.*) coral associations".

The maximum depth reached by zooxanthellate scleractinians at Osprey Reef is comparable to that observed in the Ryukyu Islands (Yamazato 1972) and in the Red Sea (Fricke & Schuhmacher 1983). According to the latter authors, this lower limit corresponds to the average depth at which the value of light intensity is approximately 1% of the surface value. Below this threshold, photoadaptation to low light intensities is no longer possible for the majority of symbiotic scleractinian species. This maximum average depth limit is approximately the same for most octocorals (with the possible exception of some *Nephtheidae* and *Suberogorgia*). In contrast, encrusting calcareous algae clearly extend deeper on the slopes than scleractinians or most octocorals and were present down to ca. 150 m. In the Red Sea the lower limit of coralline algae corresponds to approximately 0.5% of surface light intensity (Fricke & Hottinger 1983), a threshold which is interpreted by these authors as representing the lower limit of the euphotic zone.

At Osprey Reef, below the maximum depth of corals and coralline algae the benthic epifauna is extremely depauperate. This observation is in sharp contrast with the findings of Fricke & Hottinger (1983) who reported a rich development of non-symbiotic colonial corals, dominated by *Madracis interjecta* and (to a lesser extent) *Dendrophyllia minuscula*. No evidence of similar biotopes, however, has ever been suggested from the results of dredge hauls in other areas of the Indo-Pacific and it is hypothesized that the *Madracis interjecta* type of bioherms, reported by Fricke & Hottinger from the Western Gulf of Aqaba may not be a general feature of the deep sea fore reef slope in the Indo-Pacific.

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